Volumetric and Sedimentation Survey of LAKE PALO PINTO

June 2007 Survey

Prepared by:

The Texas Water Development Board

September 2008

Texas Water Development Board

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Prepared for:

Palo Pinto County Municipal Water District No. 1

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Executive Summary

In December of 2006, the Texas Water Development Board (TWDB) entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, for the purpose of performing a volumetric and sediment survey of Lake Palo Pinto. Palo Pinto Creek Dam and Lake Palo Pinto are located on Palo Pinto Creek in the Brazos River Basin 15 miles southwest of Mineral Wells in Palo Pinto County, Texas. TWDB conducted the Lake Palo Pinto survey on June 18th- 20th 2007, July 31st 2007, and on January 22nd 2008. Sediment cores were collected on January 23rd 2008.

Water surface elevations are recorded at Palo Pinto Creek Dam and published by the U.S. Geological Survey (Site 08090300). Prior to this TWDB survey, the conservation pool elevation for Lake Palo Pinto was set at 867.0 feet (NGVD 29). To clarify the accuracy of the lake conservation pool elevation and gauge datum, TWDB conducted a fast-static elevation survey of the Palo Pinto Creek Dam on August 30th and August 31st, 2007. From the results of this survey, TWDB revised the elevation of the Palo Pinto Creek Dam gauge datum, effectively changing the Lake Palo Pinto conservation pool elevation to 867.3 feet (NAVD88).

The results of the TWDB 2007 Volumetric Survey indicate Lake Palo Pinto has a total reservoir capacity of 27,215 acre-feet and encompasses 2,176 acres at conservation pool elevation (867.3 feet NAVD88). Lake Palo Pinto capacity (at conservation pool elevation) was previously estimated at 27,650 acre-feet in 1985 (by HDR Infrastructure) and 27,590 acre-feet in 1988 (by TWDB). Due to differences in the methodologies used in calculating areas and capacities from this and previous Lake Palo Pinto surveys, comparison of these values is not recommended. The TWDB considers the 2007 survey to be a significant improvement over previous methods and recommends that a similar methodology be used to resurvey Lake Palo Pinto in approximately 10 years or after a major flood event.

The results of the TWDB 2007 Sedimentation Survey indicate Lake Palo Pinto has accumulated 1,850 acre-feet of sediment since impoundment in 1964. Based on this measured sediment volume and assuming a constant rate of sediment accumulation, Lake Palo Pinto loses approximately 42 acre-feet of capacity per year.

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Lake Palo Pinto General Information

Palo Pinto Creek Dam and Lake Palo Pinto are located on Palo Pinto Creek in the Brazos River Basin 15 miles southwest of Mineral Wells in Palo Pinto County, Texas (Figure 1). Lake Palo Pinto is owned by Palo Pinto County Municipal Water District No. 1, and operated by the City of Mineral Wells. Construction on Palo Pinto Creek Dam began on March 21, 1963, with deliberate impoundment beginning on April 16, 1964. The original project was completed on April 20, 1964. A permit to raise the spillway was issued December 3, 1964 and the enlargement was completed on November 13, 1965. Lake Palo Pinto serves mainly as water supply storage for municipal and industrial uses. Additional pertinent data about Palo Pinto Creek Dam and Lake Palo Pinto can be found in Table 1.[1]

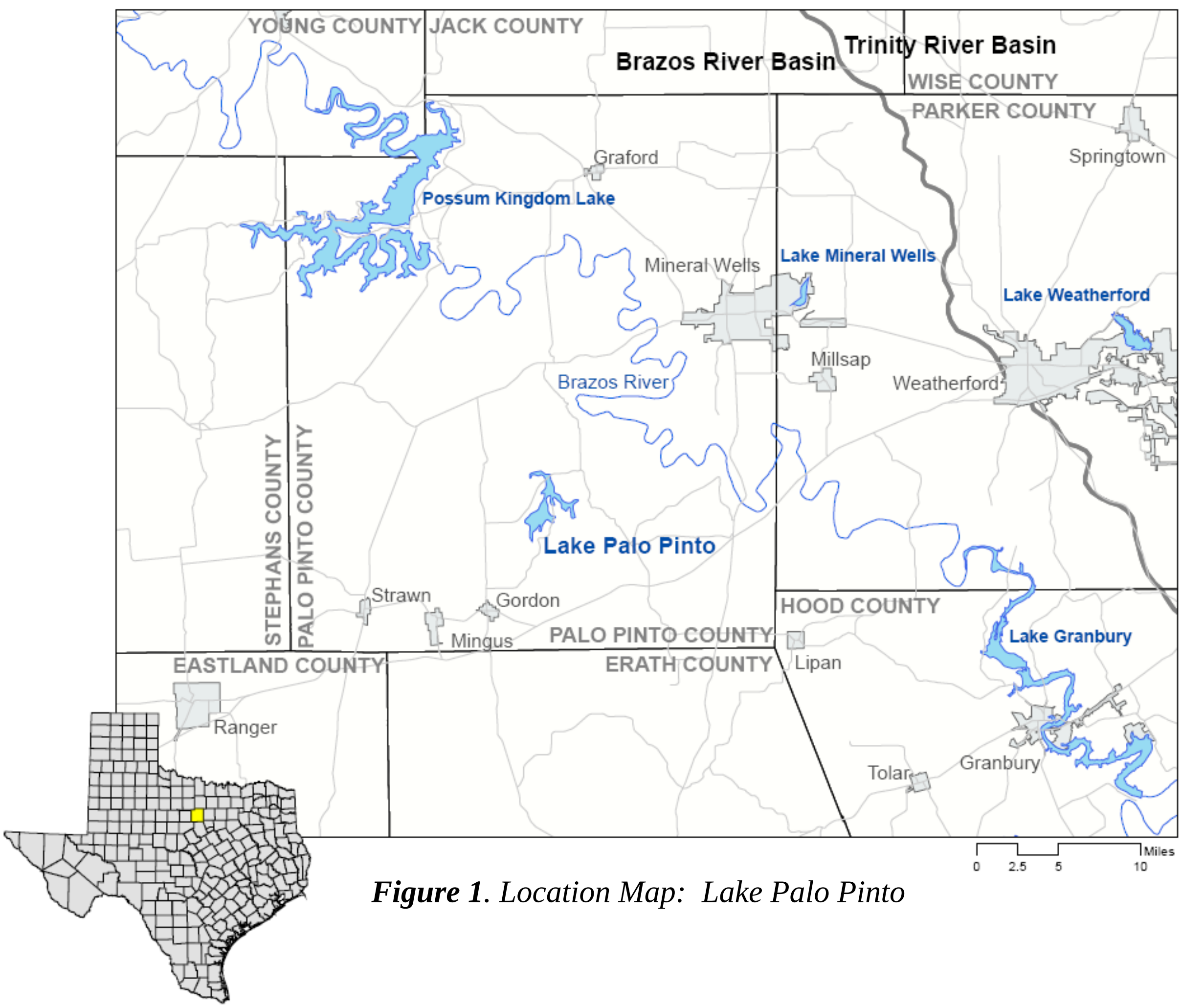


***Figure 1**. Location Map: Lake Palo Pinto*

Table 1. Pertinent Data for Palo Pinto Creek Dam and Lake Palo Pinto[1]

Owner		
	Palo Pinto County Municipal Water District No. 1. Operated by the city of Mineral Wells	
Engineer (Design)		
	Freese, Nichols and Endress for the original dam	
Location of Dam		
	On Palo Pinto Creek in Palo Pinto County, 15 miles southwest of Mineral Wells	
Drainage Area		
	471 square miles	
Dam		
	Type	Earthfill
	Length	1,255 feet
	Height	96 feet
	Top Width	22 feet
	Top elevation	898.0 feet above mean sea level***
Spillway		
	Location	Right end of dam
	Type	Concrete ogee
	Length	550 feet
	Crest elevation	867.0 feet above mean sea level***
Outlet Works		
	Type	30-inch diameter concrete pipe
	Invert elevation	835.0 feet above mean sea level***
	Control	Motor-operated valves
	Water flows in the creek to a diversion lake 12 miles downstream	

*** Elevations reported in the NGVD29 datum[1]

Water Rights

The water rights for Lake Palo Pinto have been appropriated to the Palo Pinto County Municipal Water District No. 1 through Certificate of Adjudication No. 12-4031. Palo Pinto County Municipal Water District No. 1 is authorized to impound in Lake Palo Pinto up to 44,100 acre-feet of water and impound up to 24 acre-feet of water behind a smaller dam downstream for diversion. Palo Pinto County Municipal Water District No. 1 is authorized to divert and use a maximum of 12,500 acre-feet of water per annum for municipal purposes and a maximum of 6,000 acre-feet of water per annum for industrial purposes. The time priority for the right to store 34,250 acre-feet of water in Lake Palo Pinto, divert 10,000 acre-feet of water for municipal purposes, and divert 6,000 acre-feet of water for industrial purposes is July 3, 1962. The time priority for the right to store the remaining 9,850 acre-feet of water in Lake Palo Pinto, store 24 acre-feet downstream, and divert 2,500 acre-feet of water for municipal purposes is September 8, 1964. Water may not be diverted from Lake Palo Pinto if such a diversion would result, in combination with diversions from Lake Mineral Wells, in more than 16,000 acre-feet of water per calendar year being diverted. The complete certificate is on file in the Records Division of the Texas Commission on Environmental Quality.

Volumetric and Sediment Survey of Lake Palo Pinto

Introduction

The Texas Water Development Board (TWDB) Hydrographic Survey Program was authorized by the state legislature in 1991. The Texas Water Code authorizes TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In December of 2006, the Texas Water Development Board entered into agreement with the U.S. Army Corps of Engineers, Fort Worth District, for the purpose of performing a volumetric and sediment survey of Lake Palo Pinto. This survey was performed using a single-beam multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder. The 200 kHz return measures the current bathymetric surface, while the combination of the three frequencies is analyzed for evidence of sediment accumulation throughout the reservoir. Sediment core samples are collected in order to validate the interpretation of the multi-frequency acoustic signals and to verify the identification of the reservoir bathymetric surface at the time of initial impoundment.

Datum

Water surface elevations are recorded at Palo Pinto Creek Dam and published by the United States Geological Survey (USGS). The water surface elevations recorded by this gauge, USGS 08090300 Lk Palo Pinto nr Santo, TX, are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29)[2]. The conservation pool elevation (CPE) of Lake Palo Pinto is considered 867.0 feet (NGVD 29), which is equivalent to the elevation of the crest of the Palo Pinto Creek Dam. To clarify the accuracy of the lake CPE and gauge datum, TWDB conducted a fast-static elevation survey of the Palo Pinto Creek Dam on August 30th and August 31st, 2007 (See Appendix D). From the results of this fast-static survey, TWDB revised the elevation of the Palo Pinto Creek Dam gauge datum, raising the gauge datum by 0.7 feet. TWDB also determined that the actual elevation of the Palo Pinto Dam crest is 867.3 feet North American Vertical Datum 1988 (NAVD88). As a result, TWDB considers the Lake Palo Pinto CPE to be 867.3 feet. All elevations presented in this report (unless stated otherwise) are referenced to this revised gauge datum and to the NAVD88 vertical datum. Due to the revised datums, comparisons of results from the 2007 TWDB survey presented herein with those from previous surveys require subtraction of 0.3 feet from the water surface elevations presented herein. For example, to compare the current capacity at CPE to the previously reported CPE capacity, one must compare the current capacity at 867.3 feet (NAVD88) to that previously reported at elevation 867.0 feet (NGVD29). Water surface elevations stated in this report are referenced to the NAVD88 datum and were created through the addition of 0.7 feet to the elevation recorded by the USGS gauge on the NGVD29 datum.

Volume and area tables computed from the NAVD88 datum are included in Appendix A and B, respectively. The horizontal datum used for this report is North American Datum of 1983 (NAD83) State Plane Texas North Central Zone (feet).

TWDB Bathymetric Data Collection

TWDB conducted the Lake Palo Pinto survey on June 18th, 19th, and 20th 2007, while the water surface elevation measured 868.6 feet, 867.7 feet, and 867.6 feet (NAVD88), respectively. TWDB returned to the lake to collect additional data on July 31st, 2007 while the water surface elevation measured 867.10 feet (NAVD88) and on January 22nd, 2008 while the water surface elevation measured 865.24 feet (NAVD88).

For all data collection efforts, TWDB used a Specialty Devices, Inc., multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Data collection occurred while navigating along pre-planned range lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. For all data collection efforts, the depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. The average speed of sound through the water column measured 4,921 feet per second during the data collection effort. During the 2007 survey, team members collected 47,433 data points over cross-sections totaling nearly 50 miles in length. Figure 2 shows where data points were collected during the TWDB 2007 survey.

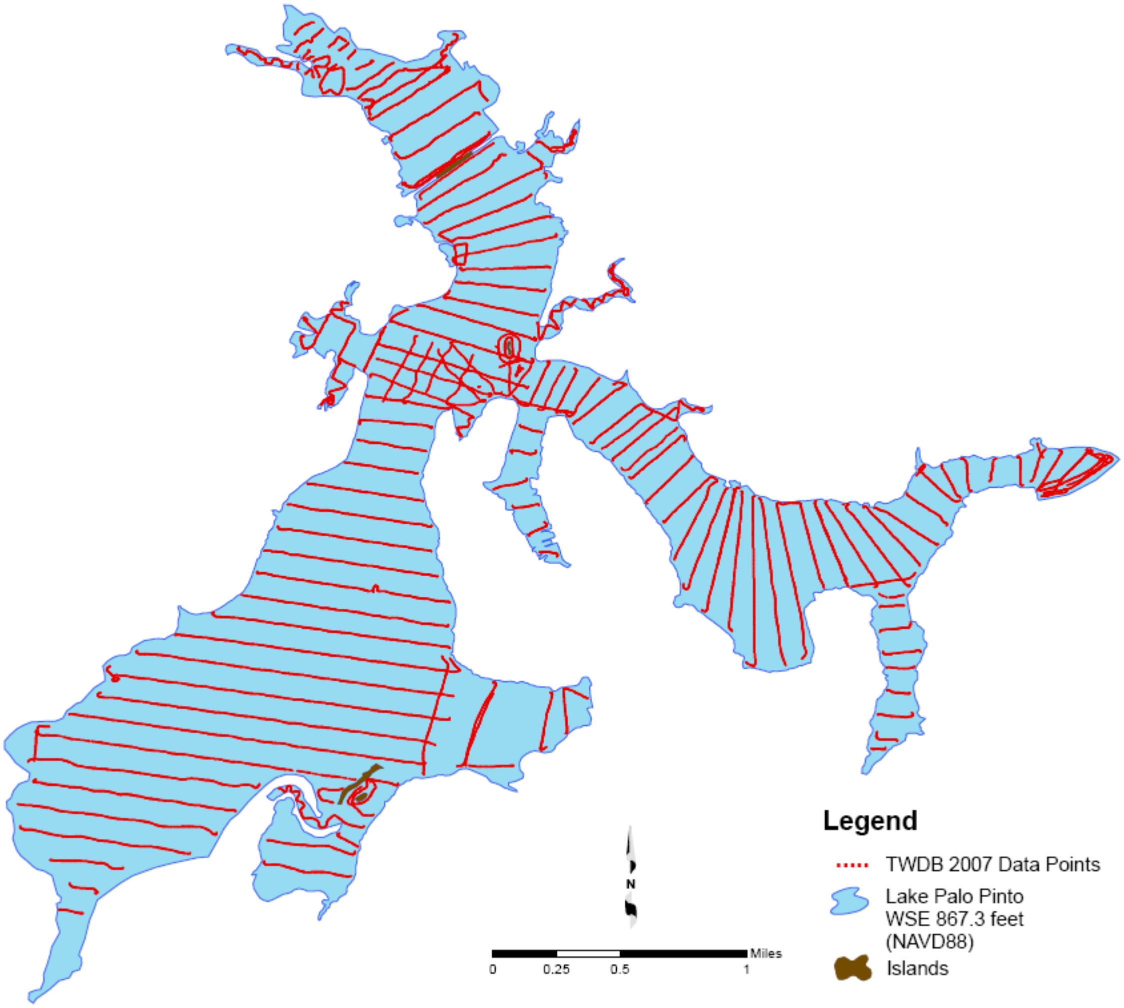


Figure 2 *– TWDB 2007 survey data points for Lake Palo Pinto*

Data Processing

Model Boundaries

A boundary of Lake Palo Pinto was digitized from aerial photographs, or digital orthophoto quarter-quadrangle images (DOQQs)[3], using Environmental Systems Research Institute's (ESRI) ArcGIS 9.1 software. The quarter-quadrangles that cover Lake Palo Pinto are Lone Camp SW, Lone Camp SE, Gordon NW, and Gordon NE. The aerial photos, with a 1-meter resolution, were taken on August 4, 2004 while the water surface elevation of Lake Palo Pinto measured 864.51 feet (NADV88). This water surface elevation represents the reservoir at 2.79 feet below conservation pool elevation, 867.3 feet (NAVD88). Therefore, ASTER Satellite Imagery was used to digitize a boundary representing 867.3 feet (NAVD88). The satellite image was taken on April 16, 2001 while the water surface elevation of Palo Pinto measured 867.36 feet (NAVD88). ASTER satellite images have a resolution of 15 meters, therefore, the vegetation line in the 2004 DOQQs and the 2004 boundary were referenced when determining where to digitize the 867.3 foot (NAVD88) boundary. The 2004 boundary, elevation 864.51 feet (NAVD88), was verified against the data collected during the survey to confirm its accuracy in areas of heavy vegetation visible in the photos and input into the reservoir model as a contour.

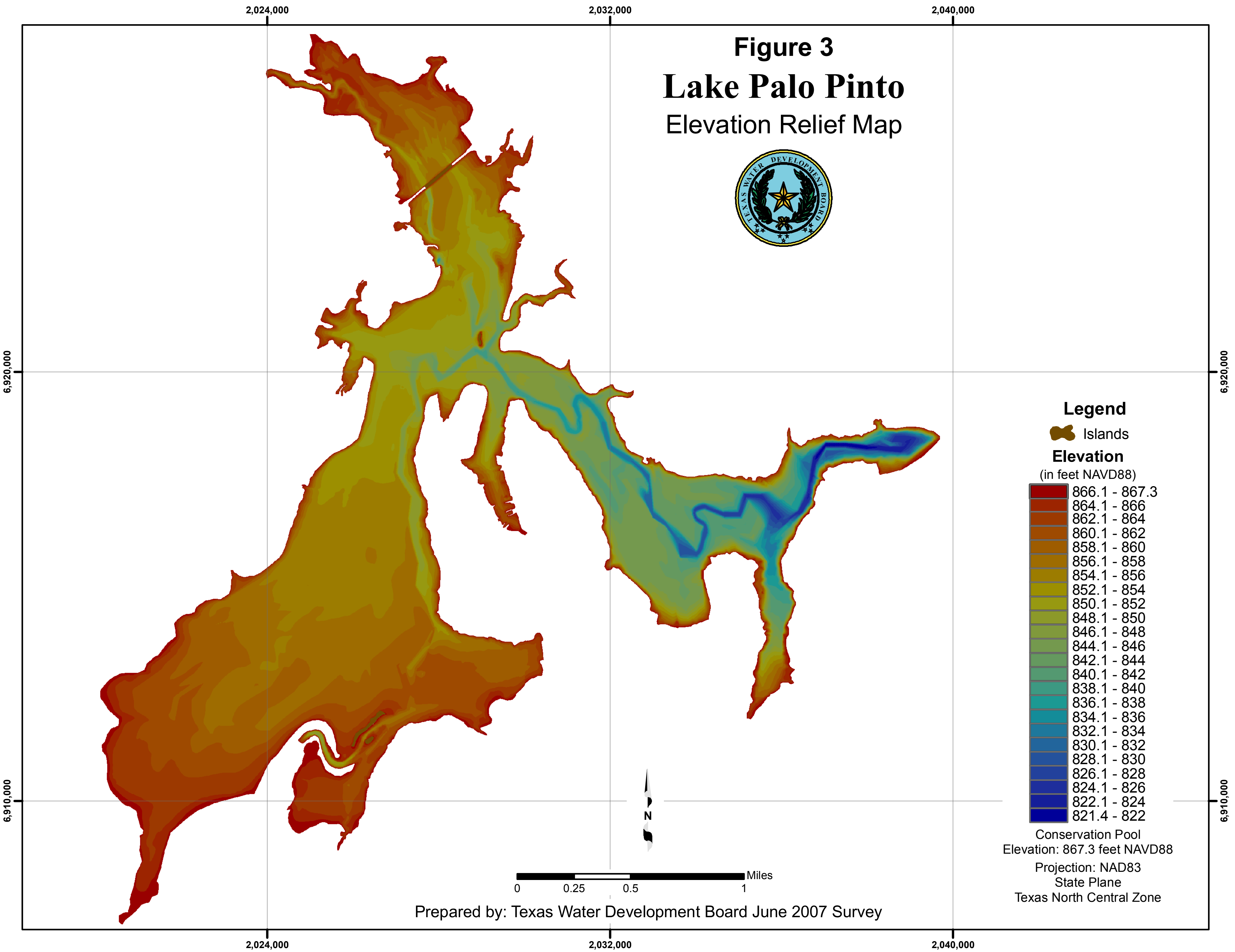
Triangular Irregular Network (TIN) Model

Upon completion of data collection, the raw data files collected by TWDB were edited using DepthPic and HydroEdit to remove any data anomalies. DepthPic is used to display, interpret, and manually-edit the multi-frequency data, while HydroEdit is used to automatically edit the multi-frequency data and to convert the depth measurements to bathymetric elevations using the known water surface elevation at the time of each sounding. For processing outside of DepthPic and HydroEdit, the sounding coordinates (X,Y,Z) are exported as a MASS points file. TWDB also created a MASS points file of interpolated data located in-between surveyed cross sections. This points file is described in the section entitled "Self-Similar Interpolation."

To create a surface representation of the Lake Palo Pinto bathymetry, the 3D Analyst Extension[4] of ArcGIS (ESRI, Inc.) is used. With this extension, a triangulated irregular network (TIN) model of the bathymetry is created following the Delaunay criteria, where each MASS point and boundary node becomes the vertex of a triangular portion of the reservoir bottom surface. From the TIN model, reservoir capacities and areas are calculated at one-tenth of a foot (0.1 foot) intervals, from elevation 821.0 feet (NAVD88) to elevation 867.3 feet (NAVD88).

The Elevation-Capacity and Elevation-Area Tables, updated for 2007, are presented in Appendices A and B, respectively. An Elevation-Area-Capacity graph is presented in Appendix C.

The TIN model was interpolated and averaged using a cell size of 1 foot by 1 foot and converted to a raster. The raster was used to produce an Elevation Relief Map representing the topography of the reservoir bottom (Figure 3), a map showing shaded depth ranges for Lake Palo Pinto (Figure 4), and a 5-ft contour map (Figure 5).



2,024,000
2,032,000
2,040,000
6,920,000
6,910,000
Figure 3
Lake Palo Pinto
Elevation Relief Map
Legend
Islands
Elevation
(in feet NAVD88)
866.1 - 867.3
864.1 - 866
862.1 - 864
860.1 - 862
858.1 - 860
856.1 - 858
854.1 - 856
852.1 - 854
850.1 - 852
848.1 - 850
846.1 - 848
844.1 - 846
842.1 - 844
840.1 - 842
838.1 - 840
836.1 - 838
834.1 - 836
832.1 - 834
830.1 - 832
828.1 - 830
826.1 - 828
824.1 - 826
822.1 - 824
821.4 - 822
Conservation Pool
Elevation: 867.3 feet NAVD88
Projection: NAD83
State Plane
Texas North Central Zone
N
Miles
0 0.25 0.5 1
Prepared by: Texas Water Development Board June 2007 Survey

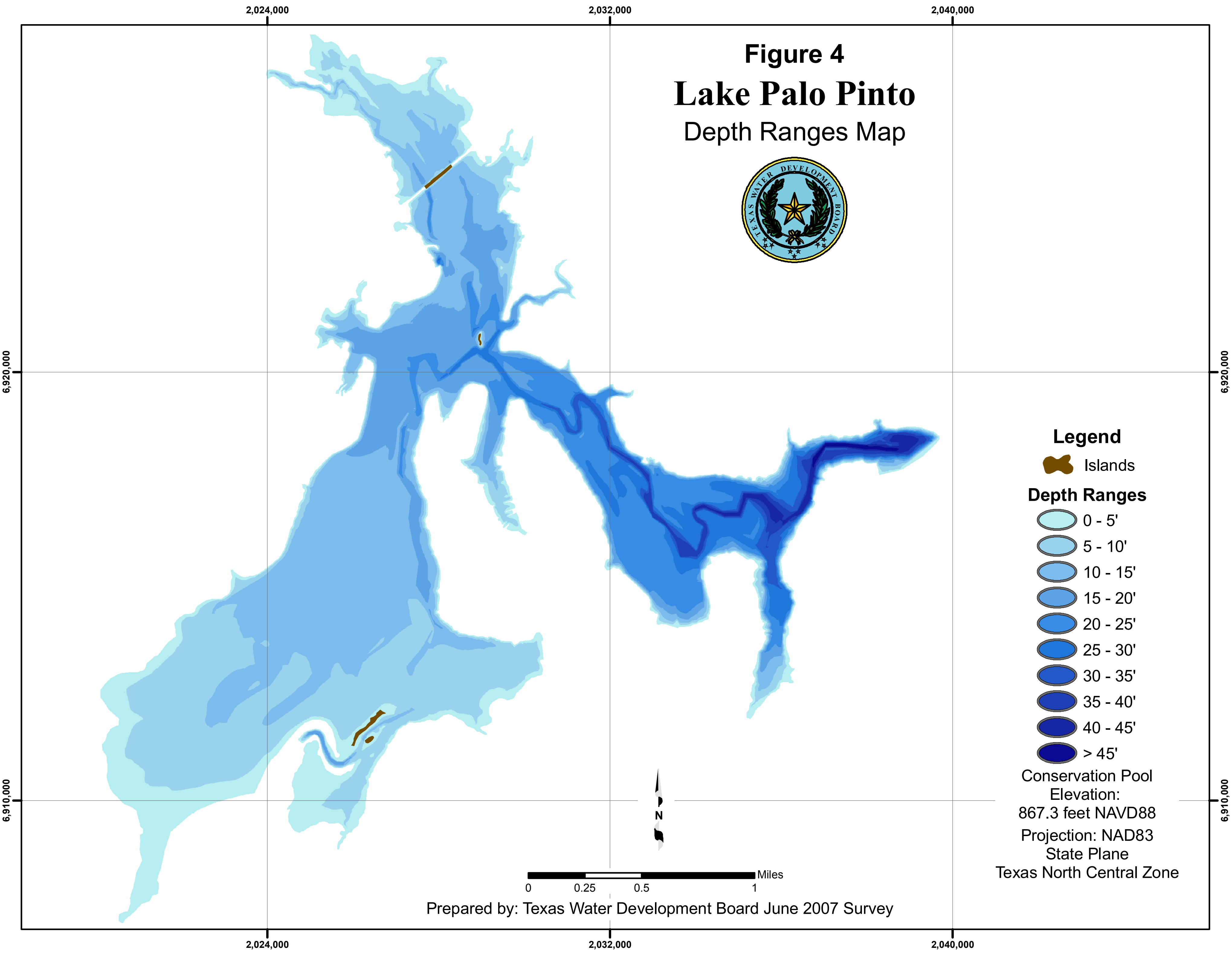


Figure 4
Lake Palo Pinto
Depth Ranges Map
TEXAS WATER DEVELOPMENT BOARD
2,024,000
2,032,000
2,040,000
6,920,000
6,910,000
Legend
Islands
Depth Ranges
0 - 5'
5 - 10'
10 - 15'
15 - 20'
20 - 25'
25 - 30'
30 - 35'
35 - 40'
40 - 45'
> 45'
Conservation Pool
Elevation:
867.3 feet NAVD88
Projection: NAD83
State Plane
Texas North Central Zone
N
0 0.25 0.5 1
Miles
Prepared by: Texas Water Development Board June 2007 Survey

Self-Similar Interpolation

A limitation of the Delaunay method for triangulation when creating TIN models results in artificially-curved contour lines extending into the reservoir where the reservoir walls are steep and the reservoir is relatively narrow. These curved contours are likely a poor representation of the true reservoir bathymetry in these areas. Also, if the surveyed cross sections are not perpendicular to the centerline of the submerged river channel (the location of which is often unknown until after the survey), then the TIN model is not likely to well-represent the true channel bathymetry.

To ameliorate these problems, a Self-Similar Interpolation routine (developed by TWDB) was used to interpolate the bathymetry in between many 500 foot-spaced survey lines. The Self-Similar Interpolation technique effectively increases the density of points input into the TIN model, and directs the TIN interpolation to better represent the reservoir topography.[5] In the case of Lake Palo Pinto, the application of Self-Similar Interpolation helped represent the lake morphology near the banks and improved the representation of the submerged river channel (Figure 6). In areas where obvious geomorphic features indicate a high-probability of cross-section shape changes (e.g. incoming tributaries, significant widening/narrowing of channel, etc.), the assumptions used in applying the Self-Similar Interpolation technique are not likely to be valid; therefore, self-similar interpolation was not used in areas of Lake Palo Pinto where a high probability of change between cross-sections exists.[5] Figure 6 illustrates typical results of the application of the Self-Similar Interpolation routine in Lake Palo Pinto, and the bathymetry shown in Figure 6C was used in computing reservoir capacity and area tables (Appendix A, B).

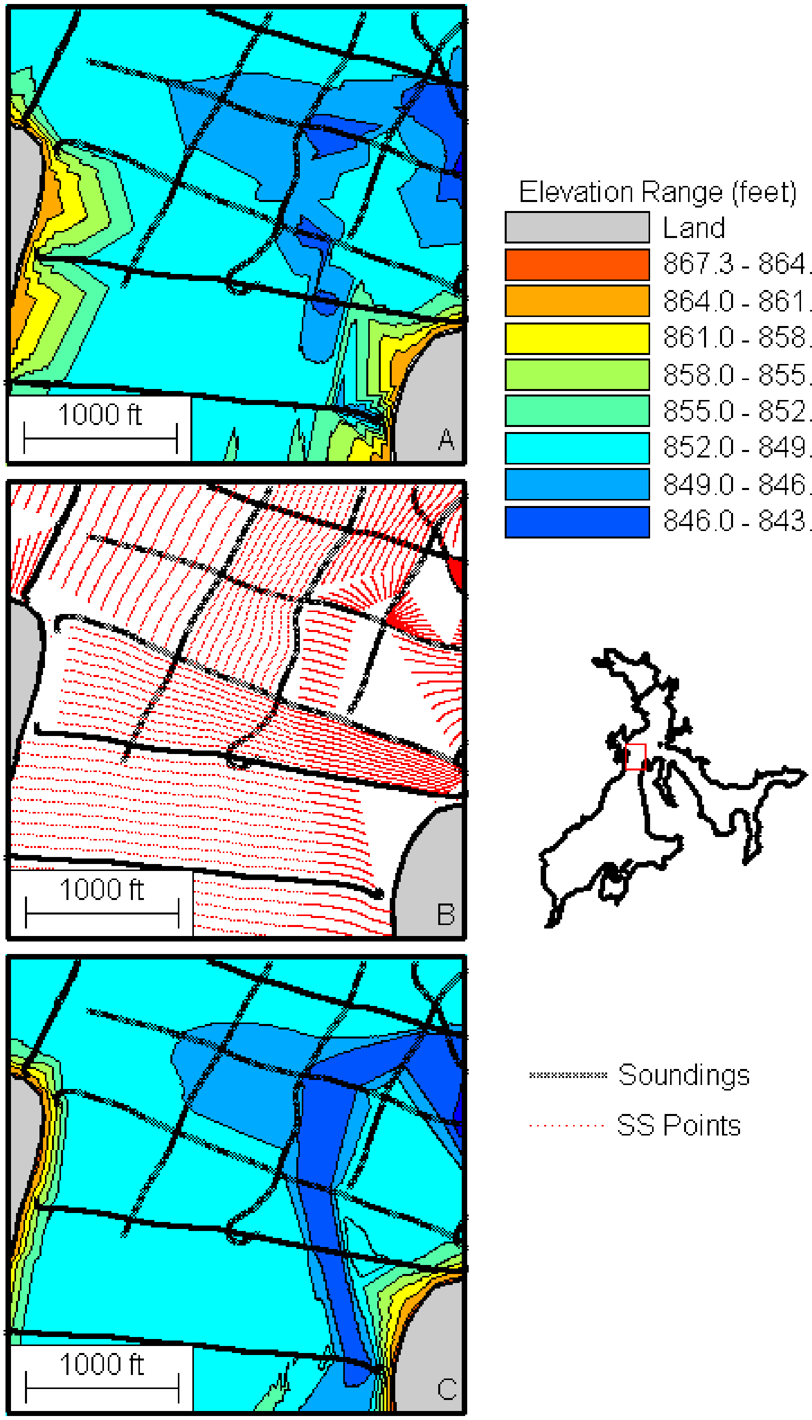


Figure 6 *- Application of the Self-Similar Interpolation technique to Lake Palo Pinto sounding data – A) bathymetric contours without interpolated points, B) Sounding points (black) and interpolated points (red) with reservoir boundary shown at elevation 867.3 feet (black), C) bathymetric contours with the interpolated points. Note: In 6A the steep banks and deep channel indicated by the surveyed cross sections are not represented for the areas in-between the cross sections. This is an artifact of the TIN generation routine when data points are too far apart. Inclusion of the interpolated points (6C) corrects this and smoothes the bathymetric contours.*

Volumetric Survey Results

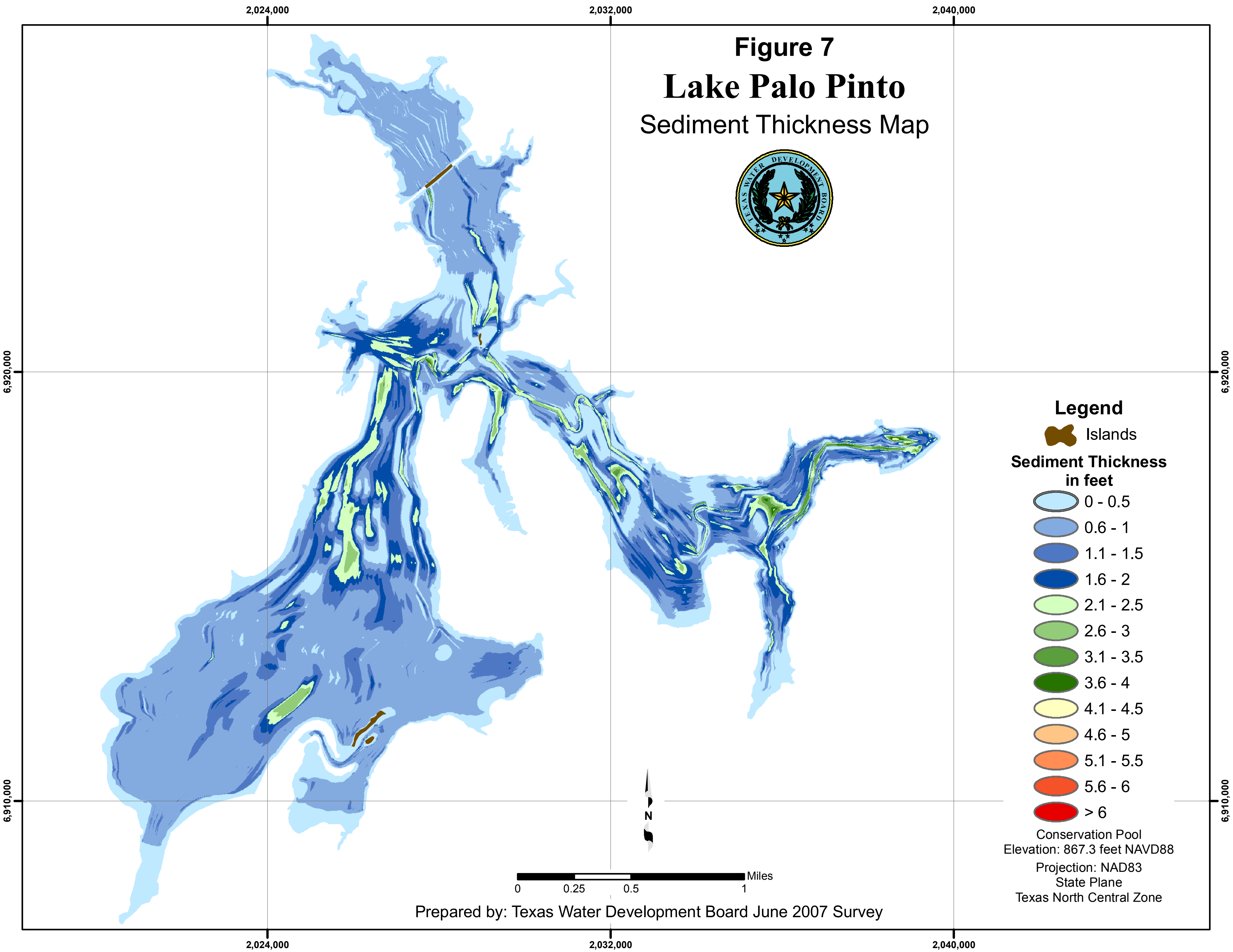
The results of the TWDB 2007 Volumetric Survey indicate Lake Palo Pinto has a total reservoir capacity of 27,215 acre-feet and encompasses 2,176 acres at conservation pool elevation (867.3 feet NAVD88). Lake Palo Pinto capacity (at conservation pool elevation) was previously estimated at 27,650 acre-feet in 1985 (By HDR Infastructure[6]) and 27,590 acre-feet in 1988 (by TWDB[7]). Due to differences in the methodologies used in calculating areas and capacities from this and previous Lake Palo Pinto surveys, comparison of these values is not recommended[8]. The TWDB considers the 2007 survey to be a significant improvement over previous methods and recommends that a similar methodology be used to resurvey Lake Palo Pinto in approximately 10 years or after a major flood event.

Sediment Survey Results

The 200 kHz, 50 kHz, and 24 kHz frequency data were used to interpret sediment distribution and accumulation throughout Lake Palo Pinto. Figure 7 shows the thickness of sediment throughout the lake. To assist in the interpretation of post-impoundment sediment accumulation, ancillary data was collected in the form of four core samples. Sediment cores were collected on January 23, 2008 using a Specialty Devices, Inc. VibraCore system.

The results of the TWDB 2007 Sedimentation Survey indicate Lake Palo Pinto has accumulated 1,850 acre-feet of sediment since impoundment in 1964. Based on this measured sediment volume and assuming a constant rate of sediment accumulation, Lake Palo Pinto loses approximately 42 acre-feet of capacity per year. Sediment is deposited mainly within the submerged channel of Palo Pinto Creek and in the areas immediately adjacent to the submerged channel banks. The maximum sediment thickness observed in Lake Palo Pinto was 6.2 feet, and sediment was observed on 1901 acres (87.3 %) of the lake bed. The average sediment thickness (in areas where sediment is present) is 0.97 feet.

A complete description of the sediment measurement methodology and sample results is presented in Appendix E.


2,024,000
2,032,000
2,040,000
Figure 7
Lake Palo Pinto
Sediment Thickness Map
TEXAS WATER DEVELOPMENT BOARD
6,920,000
6,910,000
Legend
Islands
Sediment Thickness in feet
0 - 0.5
0.6 - 1
1.1 - 1.5
1.6 - 2
2.1 - 2.5
2.6 - 3
3.1 - 3.5
3.6 - 4
4.1 - 4.5
4.6 - 5
5.1 - 5.5
5.6 - 6
> 6
Conservation Pool
Elevation: 867.3 feet NAVD88
Projection: NAD83
State Plane
Texas North Central Zone
N
Miles
0
0.25
0.5
1
Prepared by: Texas Water Development Board June 2007 Survey

TWDB Contact Information

More information about the Hydrographic Survey Program can be found at:

http://www.twdb.state.tx.us/assistance/lakesurveys/volumetricindex.asp

Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:

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Or

Jason Kemp
Team Leader, TWDB Hydrographic Survey Program
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Email: Jason.Kemp@twdb.state.tx.us

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4. ESRI, Environmental Systems Research Institute. 1995. ARC/INFO Surface Modeling and Display, TIN Users Guide.

5. Furnans, Jordan. Texas Water Development Board. 2006. "HydroEdit User's Manual."

6. HDR Infrastructure, Inc. (1985), "Sediment Survey of Lake Palo Pinto." Partial copies available from TWDB.

7. Texas Water Development Board (1988) – Inter-office memorandum "Sedimentation Survey of Lake Palo Pinto". Prepared by Mike Lynn, November 21, 1988. Copies available from TWDB.

8. United States Department of Agriculture, Natural Resource Conservation Service, National Engineering Handbook, Section 3, Sedimentation, Chapter 7, Field Investigations and Surveys, December 1983.

Appendix A

Lake Palo Pinto

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | 2007 SURVEY

CAPACITY IN ACRE-FEET | Conservation Pool Elevation 867.3 feet NAVD88

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
821	0	0	0	0	0	0	0	0	0	0
822	1	1	1	2	2	2	3	3	3	4
823	4	5	5	6	6	7	7	8	8	9
824	10	10	11	12	12	13	14	15	16	17
825	17	18	19	20	22	23	24	25	26	28
826	29	30	31	33	34	36	37	39	40	42
827	44	45	47	49	51	53	55	57	59	61
828	63	65	67	70	72	74	77	79	82	84
829	87	89	92	95	98	100	103	106	110	113
830	116	119	122	126	129	133	136	140	144	147
831	151	155	159	163	167	172	176	180	185	189
832	194	198	203	208	213	218	223	228	233	238
833	244	249	255	260	266	272	277	283	289	295
834	301	308	314	320	327	333	340	346	353	360
835	367	374	381	388	395	402	410	417	425	433
836	441	448	456	465	473	481	489	498	507	515
837	524	533	542	551	560	569	579	588	598	608
838	618	627	638	648	658	668	679	690	700	711
839	722	733	745	756	768	780	792	804	816	828
840	841	853	866	879	893	907	920	935	949	964
841	979	994	1,009	1,025	1,041	1,057	1,073	1,090	1,107	1,124
842	1,141	1,159	1,177	1,195	1,213	1,232	1,252	1,272	1,292	1,312
843	1,333	1,355	1,376	1,398	1,421	1,443	1,466	1,490	1,514	1,538
844	1,563	1,588	1,614	1,640	1,667	1,694	1,722	1,751	1,780	1,810
845	1,840	1,871	1,903	1,935	1,968	2,001	2,034	2,069	2,103	2,138
846	2,173	2,209	2,245	2,281	2,318	2,355	2,392	2,430	2,468	2,506
847	2,545	2,584	2,624	2,663	2,704	2,744	2,785	2,827	2,868	2,910
848	2,953	2,995	3,038	3,081	3,125	3,169	3,213	3,257	3,302	3,347
849	3,392	3,437	3,483	3,529	3,575	3,622	3,669	3,716	3,763	3,811
850	3,860	3,908	3,957	4,007	4,056	4,107	4,157	4,208	4,260	4,312
851	4,365	4,418	4,471	4,526	4,581	4,636	4,693	4,750	4,807	4,865
852	4,925	4,985	5,046	5,107	5,170	5,233	5,297	5,363	5,429	5,496
853	5,563	5,632	5,701	5,771	5,841	5,912	5,984	6,057	6,130	6,204
854	6,279	6,355	6,431	6,509	6,587	6,666	6,747	6,828	6,910	6,995
855	7,080	7,167	7,256	7,347	7,439	7,533	7,629	7,725	7,824	7,923
856	8,024	8,126	8,230	8,334	8,440	8,547	8,655	8,764	8,874	8,986
857	9,099	9,213	9,329	9,447	9,566	9,688	9,811	9,935	10,061	10,189
858	10,317	10,447	10,579	10,711	10,845	10,980	11,116	11,254	11,392	11,532
859	11,674	11,816	11,960	12,106	12,253	12,401	12,550	12,701	12,853	13,006
860	13,159	13,314	13,471	13,628	13,786	13,945	14,105	14,267	14,430	14,594
861	14,759	14,926	15,094	15,263	15,434	15,606	15,779	15,954	16,130	16,307
862	16,485	16,664	16,844	17,025	17,208	17,391	17,575	17,761	17,948	18,136
863	18,325	18,515	18,706	18,898	19,091	19,285	19,480	19,676	19,873	20,071
864	20,270	20,470	20,670	20,872	21,075	21,279	21,485	21,693	21,900	22,108
865	22,316	22,525	22,734	22,943	23,153	23,363	23,574	23,785	23,996	24,208
866	24,420	24,633	24,846	25,059	25,273	25,487	25,702	25,917	26,132	26,348
867	26,564	26,780	26,997	27,215						

Appendix B

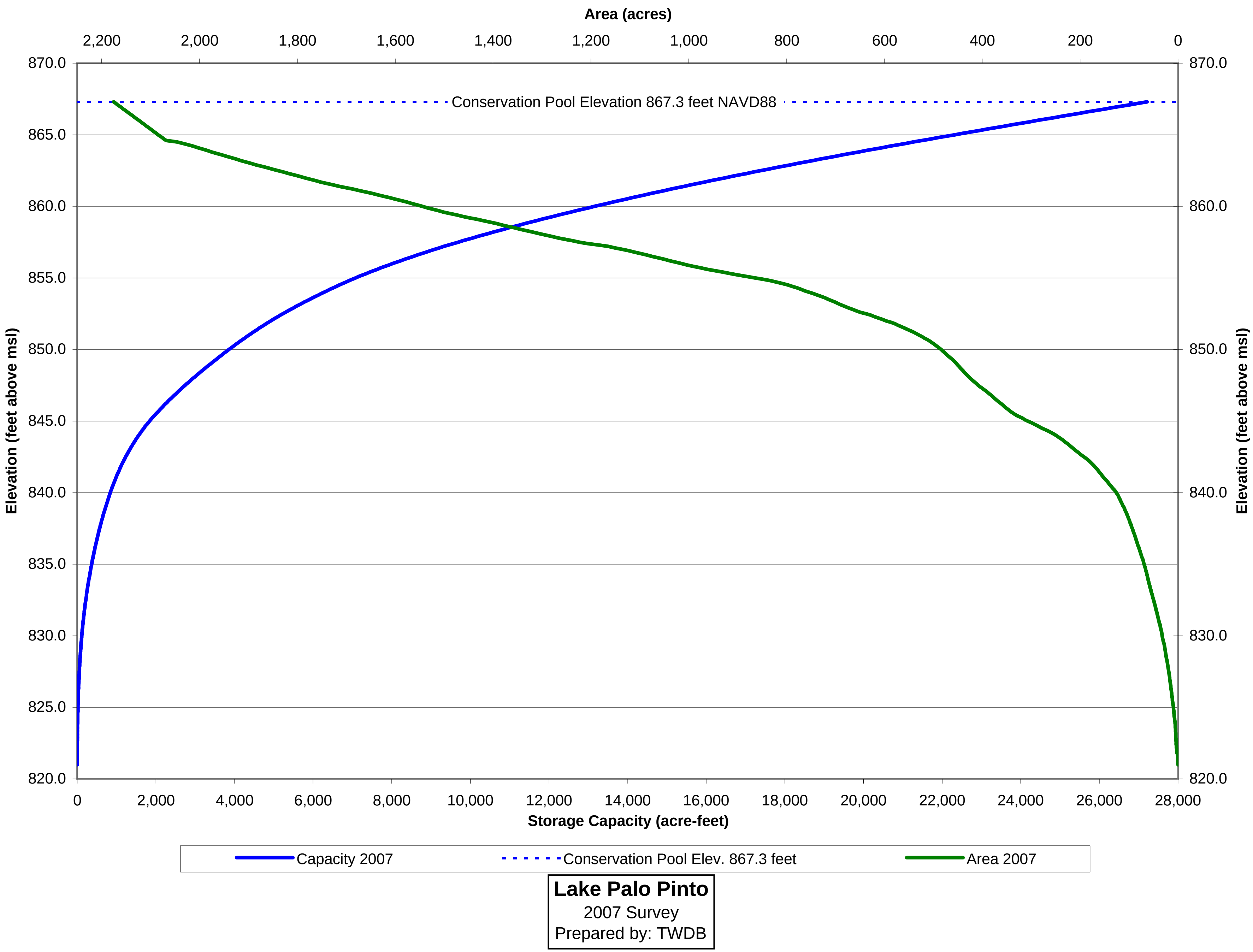
Lake Palo Pinto

RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD
AREA IN ACRES
ELEVATION INCREMENT IS ONE TENTH FOOT

2007 SURVEY
Conservation Pool Elevation 867.3 feet NAVD88

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
821	0	0	0	0	0	0	1	1	2	2
822	2	3	3	3	3	4	4	4	4	4
823	5	5	5	5	5	5	5	6	6	6
824	6	7	7	7	8	8	8	8	9	9
825	9	10	10	11	11	11	12	12	12	13
826	13	13	14	14	15	15	15	16	16	17
827	17	17	18	18	19	19	20	20	21	21
828	21	22	22	23	23	24	24	25	25	26
829	26	27	27	28	28	29	30	31	31	32
830	32	33	33	34	35	35	36	36	37	38
831	39	40	40	41	42	42	43	44	45	45
832	46	47	47	48	49	50	51	52	52	53
833	54	55	56	56	57	58	59	59	60	61
834	62	62	63	64	64	65	66	67	68	68
835	69	70	71	72	73	74	75	76	77	78
836	79	80	81	82	83	83	84	85	86	87
837	88	89	90	91	92	94	95	96	97	98
838	99	100	101	102	103	105	106	107	108	110
839	111	113	114	115	117	118	120	121	123	124
840	126	128	130	133	136	138	140	143	145	148
841	150	153	155	158	160	162	164	167	170	172
842	175	178	181	184	188	192	196	200	204	208
843	211	215	218	222	225	229	233	237	241	245
844	250	254	259	265	271	278	284	289	294	301
845	307	313	318	324	330	335	339	343	347	351
846	354	358	361	365	369	372	375	378	382	385
847	389	392	396	401	405	408	412	415	418	422
848	425	428	431	434	437	439	442	444	447	450
849	453	455	458	461	465	468	471	475	478	481
850	484	488	492	496	500	504	508	513	518	524
851	529	534	540	546	553	560	566	573	579	587
852	596	605	613	621	628	638	649	658	665	673
853	681	687	694	701	707	714	722	729	737	745
854	754	763	771	778	787	797	808	819	833	848
855	864	882	899	914	930	946	962	976	990	1,003
856	1,015	1,027	1,039	1,050	1,062	1,074	1,086	1,099	1,111	1,123
857	1,137	1,151	1,165	1,185	1,206	1,223	1,238	1,253	1,267	1,280
858	1,293	1,306	1,319	1,331	1,344	1,356	1,369	1,381	1,393	1,406
859	1,419	1,434	1,449	1,462	1,475	1,488	1,501	1,512	1,523	1,534
860	1,545	1,555	1,566	1,576	1,587	1,599	1,611	1,623	1,635	1,647
861	1,659	1,673	1,686	1,700	1,714	1,727	1,740	1,752	1,764	1,774
862	1,785	1,796	1,807	1,818	1,829	1,840	1,851	1,862	1,873	1,884
863	1,895	1,905	1,915	1,925	1,935	1,945	1,955	1,965	1,975	1,984
864	1,994	2,003	2,013	2,023	2,034	2,047	2,068	2,072	2,076	2,080
865	2,084	2,088	2,092	2,096	2,100	2,104	2,108	2,112	2,116	2,120
866	2,124	2,128	2,132	2,136	2,140	2,144	2,148	2,152	2,156	2,160
867	2,164	2,168	2,172	2,176						



Appendix C: Area and Capacity Curves

Appendix D

Hydrographic Survey of Lake Palo Pinto (Texas)

GPS Measurement Report

Prepared by Jordan Furnans Ph.D., P.E.
Texas Water Development Board
June 12, 2008

Introduction

As part of its volumetric and sedimentation survey of Lake Palo Pinto, the Texas Water Development Board (TWDB) was required to produce a bathymetry dataset containing the elevation for all points within the lake. To create this dataset, water depths were measured with boat-mounted sonar equipment, and lake bottom elevations were calculated by subtracting the water depth from the water surface elevation measured at the Palo Pinto Creek Dam gauge (USGS Site 08090300 Lk Palo Pinto nr Santo, TX)[1]. To verify the accuracy of the USGS gauge datum and lake conservation pool elevation, TWDB performed a fast-static GPS elevation survey on August 30th, 2007 and August 31st, 2007. The GPS measurements were tied-in to the local National Geodetic Survey benchmark system by referencing the known elevations at five benchmarks in the vicinity of Lake Palo Pinto. This appendix describes the GPS survey and how the data was processed, the establishment of a revised conservation pool elevation for Lake Palo Pinto, and the establishment of a revised gauge datum for Palo Pinto Creek Dam.

Surveyor in charge:

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Texas Water Development Board

Assistant Surveyor:

Randall Burns
Texas Water Development Board

Basic Surveying Methodology

In general, accurate land surface elevation measurements may be measured using a fast-static survey in which one GPS receiver (the “Base”) is stationary and a second GPS receiver (the “Rover”) is moved to the areas at which elevations are to be determined. The Base station receives a longer period of satellite signals, and therefore obtains a more accurate “fix” of its position on the Earth based on those signals. The Rover station receives the same signals as the Base station, however the period of time at which the rover is located at a given location is much shorter. This reduces the accuracy of the absolute Rover position fixes, however the Rover position relative to the Base station position retains a high level of accuracy. Upon completion of the data collection, data from the Base and Rover receivers are correlated to provide the highest possible accuracy of the position fixes at the Rover station locations. Data post-processing is performed using the Trimble Geomatics Office software, from which point elevations are derived.

To properly reference the Base and Rover positions to any of the various existing surveying datums/reference systems, measurements are made with the Rover located above numerous known elevation/position benchmarks established by the National Geodetic Survey (NGS). Information on regional NGS benchmarks is downloadable from the NGS website (http://www.ngs.noaa.gov/), and consists of the benchmark location, coordinates, elevation, stability, and quality of the benchmark. TWDB typically requires the use of only first-order vertically accurate benchmarks in elevation surveys, however higher-order (less accurate) benchmarks are occasionally used in the absence of more accurate benchmarks. When possible, TWDB collects Rover position data on at least five (5) established benchmarks, and uses two of the five marks in establishing the elevations of non-benchmark Rover station locations. The remaining three benchmarks are used as validation measurements, where the elevations computed at the benchmarks using the GPS data are compared with the benchmark published elevations. These comparisons are indicative of the accuracy of the GPS measurements, and this accuracy can be assumed to also pertain to the measurements made at all of the Rover station locations.

To further assure high accuracy of the GPS measurements, TWDB strives to collect redundant measurements with both the Base and Rover stations. Ideally, this process involves

1) Setup #1 - Setting up the Base station at point “A”
2) Using the Rover to collect measurements at point “B” and all other points of interest including benchmarks
3) Setup #2 - Setting up the Base station at point “B”
4) Using the Rover to collect measurements at point “A” and at least one other point of interest surveyed with the Rover during Setup #1.
5) Post-Processing the collected data to create a “triangulated baseline” linking the Base station locations from Setup#1 and Setup #2 with a Rover station location surveyed during both setups.

The “triangulated baseline” created through the duplication of measurements is a set of highly-accurate baseline elevation data that improves the processing of all GPS data collected during the fast-static survey. A diagrammatic schematic of the ideal surveying procedure is shown in Figure D1.

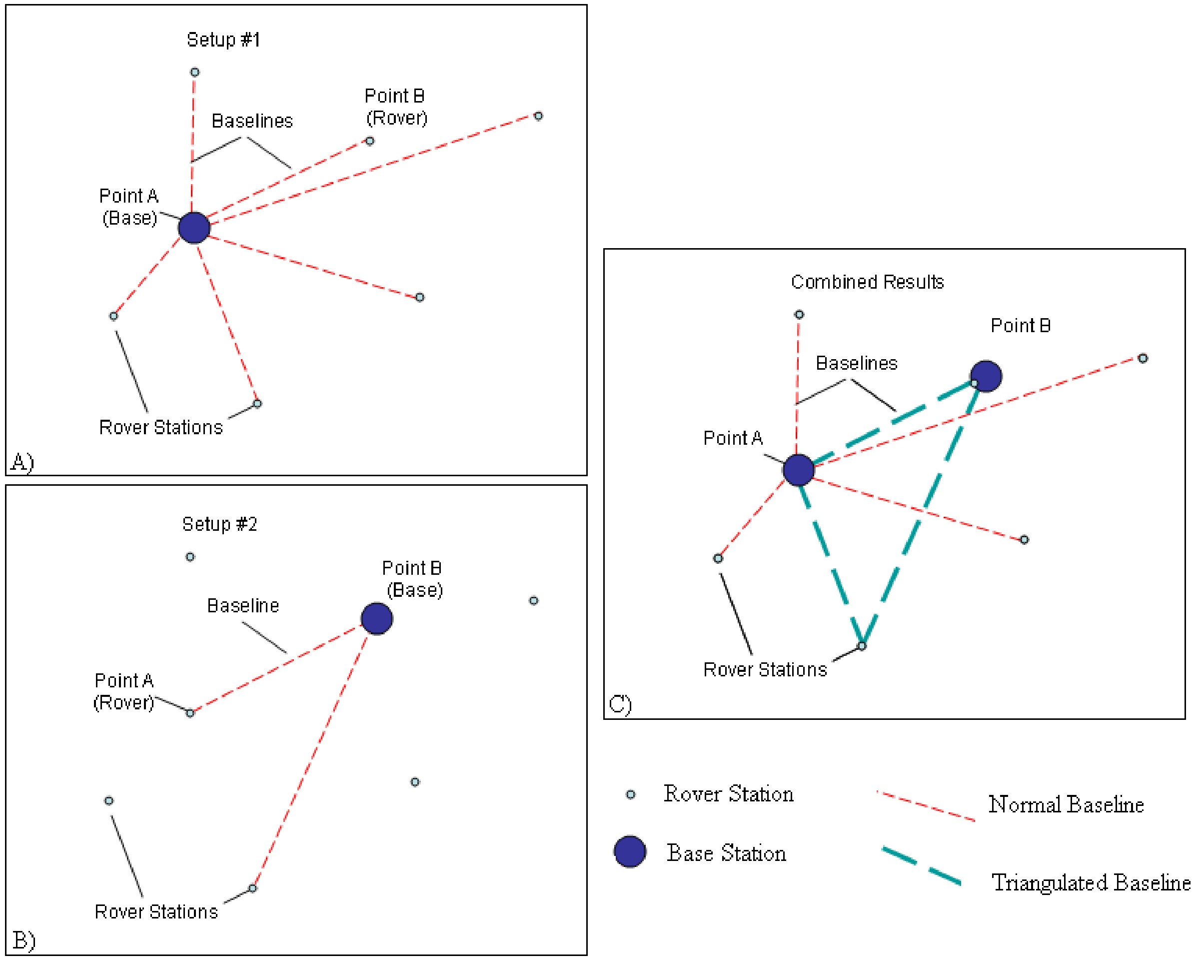


Figure D1 – Creating triangulated baselines with a fast-static survey – A) Setup #1 involves the locating the Base station at point A and collecting Rover data at all other points of interest, including point B, B) Setup #2 involves locating the Base station at point B and collecting Rover data at point A and at least one of the previously surveyed Rover stations, C) Combining the results from Setup #1 and Setup #2 in data post-processing creates a triangulated baseline of highly-accurate GPS data.

The best scenario for creating a triangulated baseline is to establish one or both of the Base station locations (points A and B) on a benchmark of known position/elevation. Often however, this is not possible as the benchmarks tend to be located in unsecure areas where equipment could be damaged if left unsupervised for long periods of time (as is needed when collecting Base station data). When surveying reservoir elevations, TWDB usually establishes Base station locations in open yet protected locations, often within gated enclosures of reservoir facilities. As such, it is important to establish the Base station locations (points A and B) as far apart as possible in order to create a triangulated baseline that is nearly equilateral. Greater accuracy in the post-processed point locations is often achieved when the triangulated baseline closely approximates and equilateral triangle.

Surveying Methodology Employed at Lake Palo Pinto

To verify the water surface elevations reported at the Palo Pinto Creek Dam gauge (USGS 08090300 Lk Palo Pinto nr Santo, TX)[1], TWDB performed a fast-static survey using a Trimble 5700 base station and a Trimble 5800 roving station. TWDB collected data at five (5) NGS benchmarks, two (2) base station locations, two (2) points along the lake shore, and at the crest of the Palo Pinto Creek dam. The elevations computed at the two (2) points along the lake shore correspond to water surface elevation measurements, and one (1) additional water surface elevation measurement was made using a differential level-loop from one of the base station locations. The three (3) resulting water surface elevation measurements were used in revising the USGS gauge datum. Table D1 summarizes the points surveyed, providing the dates of the survey, the point type surveyed, and the published elevation of the surveyed point (if the point was part of the NGS benchmark system. The location of each surveyed point is shown in Figure D2.

Table D1 – GPS Survey Sampling Point Descriptions

Point Name	Date	Survey Start	Survey Finish	Survey Type	Point Type	Published Elevation (NAVD88)
Base 1 (Point A)	8/30/07	12:38	20:11	Base	Temporary	N/A
GPS 1 (Point B)	8/30/07	13:15	13:31	Rover	Temporary	N/A
WS-Level**	8/30/07	13:24	13:24	Level	Water Surface	N/A
WS-GPS2	8/30/07	14:11	14:30	Rover	Water Surface	N/A
CT0023	8/30/07	15:27	15:42	Rover	Benchmark	812.75 ft
CT0013	8/30/07	16:10	16:26	Rover	Benchmark	800.30 ft
CT0253	8/30/07	18:22	18:37	Rover	Benchmark	1079.75 ft
CT0035	8/30/07	19:23	19:44	Rover	Benchmark	941.34 ft
GPS 1 (Point B)	8/31/07	8:08	12:43	Base	Temporary	N/A
Base 1 (Point A)	8/31/07	8:19	8:34	Rover	Temporary	N/A
CT0035	8/31/07	9:23	9:41	Rover	Benchmark	941.34 ft
CT0911	8/31/07	10:06	10:22	Rover	Benchmark	924.58 ft
CT0023	8/31/07	10:46	11:03	Rover	Benchmark	812.75 ft
Dam Crest	8/31/07	11:36	11:56	Rover	Temporary	N/A
Dam WS	8/31/07	11:58	12:13	Rover	Water Surface	N/A

**The elevation at point "WS-Level" was calculated from a differential level-loop based from point GPS1 (Point B). Water surface elevation measurements are indicated by the grey shading
***Base station locations are shown in Red

Due to security concerns, both Base station locations were located on the property of the Brazos Power & Electric Company adjacent to Lake Palo Pinto. Station "Base1 (Point A)" was used as the Base station location for setup #1 on August 30, 2007. Station "GPS1 (Point B)" was used as the Base station location for setup #2 on August 31, 2007. Duplicate Rover measurements were made at NGS benchmarks CT0035 and CT0023 in order to form triangulated baselines. The post-processing schematic used by Trimble Geomatics Office in computing point positions is shown in Figure D3.

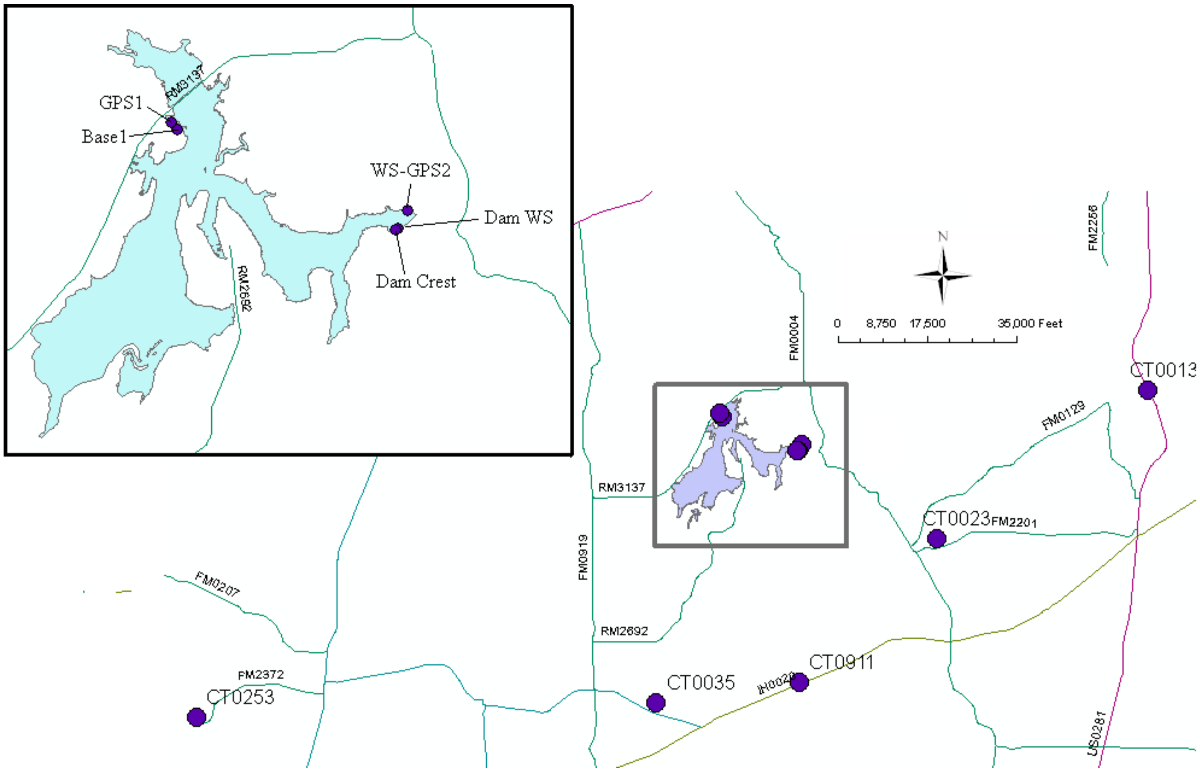


Figure D2 – GPS Survey Locations for Lake Palo Pinto

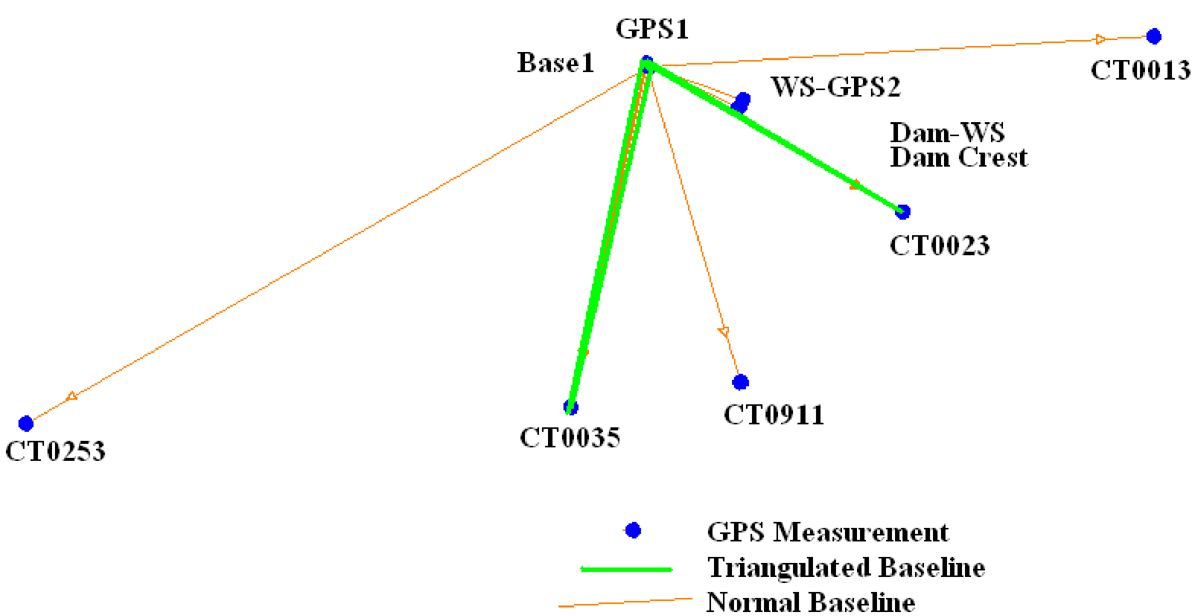


Figure D3 – Post-Processing Schematic for Lake Palo Pinto – triangulated baselines are shown in green.

Using the post-processing schematic, point elevations were computed with the Trimble Geomatics Office software while "fixing" the elevations of benchmarks CT0023 and CT0035. The resulting point positions, elevations, and measurement errors are shown in Table D2. The accuracy of the surveyed GPS point elevations was determined to be high (±0.045 ft), based on a comparison between the known and measured elevations at benchmarks CT0013, CT0253, and CT0911. From the GPS measurements, the exact elevation of the Palo Pinto Creek Dam crest (which corresponds to the Lake Palo Pinto conservation pool elevation) is 867.36 ± 0.045 ft (NAVD88). Rounding downward to a single significant digit yields:

Lake Palo Pinto Conservation Pool Elevation = 867.3 feet (NAVD88)

Table D2 – GPS Data Processing Results for Lake Palo Pinto

GPS Point	Latitude	Longitude	Published Elevation (NAVD88)	Measured Elevation (NAVD88)	Elevation Difference
Base1	32.65901643°	-98.30807579°		885.072 ft	
GPS1	32.66012341°	-98.30903946°		883.196 ft	
Dam Crest	32.64513836°	-98.27171893°		867.357 ft	
Dam WS	32.64507457°	-98.27204559°		867.227 ft	
WS-GPS2	32.64776337°	-98.27011863°		867.281 ft	
CT0023	32.60945193°	-98.2057727°	812.75 ft	812.750 ft	
CT0013	32.66905979°	-98.10433904°	800.30 ft	800.319 ft	0.019 ft
CT0253	32.53772643°	-98.55934765°	1079.75 ft	1079.681 ft	0.069 ft
CT0035	32.54330585°	-98.33978354°	941.34 ft	941.340 ft	
CT0911	32.55158598°	-98.27127292°	924.58 ft	924.611 ft	0.031 ft
			RMS Difference =		0.045 ft

**The water surface elevation measured by differential leveling from point GPS1 was calculated as: E_{GPS1} – 15.99 ft = 883.196 ft – 15.99 ft = 867.206 ft (NAVD88)

The USGS gauge datum at Palo Pinto Creek Dam was revised by comparing the measurements from Table D2 to the water surface elevations recorded at the gauge[1] at the time of the GPS measurements. The software program VERTCON[2] (published by the National Geodetic Survey) was used to convert the water surface elevations at Palo Pinto Creek Dam reported by the USGS from the NGVD29 to NAVD88 datums. For the dam location, the datum conversion equation is:

$$E_{NAVD88} = E_{NGVD29} + 0.259183 \text{ feet}$$

The water surface elevation analysis data is provided in Table D3. As shown, the RMS difference between the measured and published water surface elevations is 0.693 ft, with the measured values larger than the published values.

Table D3 –Published and Measured water surface elevations for Lake Palo Pinto

Point	Date	Time	Gauge Reading (NGVD29)	Gauge Reading (NAVD88)	GPS Elevation (NAVD88)	Elevation Difference
WS-Level	8/30/2007	13:24	866.300 ft	866.559 ft	867.206 ft	0.647 ft
WS-GPS2	8/30/2007	14:10	866.290 ft	866.549 ft	867.281 ft	0.732 ft
Dam WS	8/31/2007	11:57	866.270 ft	866.529 ft	867.227 ft	0.698 ft
				RMS Difference =		0.693 ft

Conclusions

Based on the GPS survey data reported herein, the elevation of the crest of Palo Pinto Creek Dam is:

$$E_{Crest} = 867.36 \text{ feet} \pm 0.045 \text{ feet NAVD88}$$

The conservation pool elevation (CPE) for Lake Palo Pinto is technically identical to the elevation of the crest of Palo Pinto Creek Dam. As TWDB tabulates reservoir capacities and areas at 0.1 foot increments, and given the uncertainty in the crest elevation, limiting the CPE elevation to a 0.1 foot increment is justifiable. Therefore the Lake Palo Pinto CPE is:

$$E_{CPE} = 867.3 \text{ feet NAVD88}$$

The datum for the USGS gauge at Palo Pinto Creek Dam, based on the NAVD88 datum, is given as:

$$D_{NAVD88} = D_{USGS} + 0.7 \text{ feet}$$

Where D_{USGS} is the published gauge datum (0 feet mean sea level or NGVD29) cited on the USGS gauge information sheets. The value of “0.7 feet” was used for the above datum conversion rather than the value “0.693 feet” as shown in Table D3 as the small number of water surface measurements does not warrant the precision implied by three significant digits. The above datum conversion should be used when converting surveyed depth measurements to Lake Palo Pinto bathymetric elevations based on the water surface elevations measured at the USGS gauge on Palo Pinto Creek Dam.

References

[1]http://waterdata.usgs.gov/tx/nwis/uv/?site_no=08090300

[2]http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html

Appendix E

Analysis of Sedimentation Data from Lake Palo Pinto

Executive Summary

The results of the TWDB 2007 Sedimentation Survey indicate Lake Palo Pinto has accumulated 1,850 acre-feet of sediment since impoundment in 1964. Based on this measured sediment volume and assuming a constant rate of sediment accumulation, Lake Palo Pinto loses approximately 42 acre-feet of capacity per year. Sediment is deposited mainly within the submerged channel of Palo Pinto Creek and in the areas immediately adjacent to the submerged channel banks. The maximum sediment thickness observed in Lake Palo Pinto was 6.2 feet, and sediment was observed on 1901 acres (87.3 %) of the lake bed. The average sediment thickness (in areas where sediment is present) is 0.97 feet.

Introduction

This appendix includes the results of the sediment investigation using multi-frequency depth sounder data collected on June 18-20 and July 31, 2007 and January 22, 2008 by the Texas Water Development Board (TWDB). Through careful analysis and interpretation of the multi-frequency signal returns, it is possible to discern the pre-impoundment bathymetric surface, as well as the current surface and sediment thickness. Such interpretations are aided and validated through comparisons with sediment core samples which provide independent measurements of sediment thickness. On January 23, 2008 TWDB collected four core samples of the impoundment bottom throughout the reservoir. The remainder of this appendix presents a discussion of the results from and methodology used in the core sampling and multi-frequency data collection efforts, followed by a composite analysis of sediment measured in Lake Palo Pinto.

Data Collection & Processing Methodology

TWDB conducted the Lake Palo Pinto survey on June 18th, June 19th, and June 20th of 2007, while the water surface elevation measured 868.6 feet, 867.7 feet, and 867.6 feet (NAVD88), respectively. TWDB returned to the lake to collect additional data on July 31, 2007 while the water surface elevation measured 867.10 feet (NAVD88) and on January 22, 2008 while the water surface elevation measured 865.24 feet (NAVD88).

For all data collection efforts, TWDB used a Specialty Devices, Inc., multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Data collection occurred while navigating along pre-planned range lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. For all data collection efforts, the depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. The average speed of sound through the water column measured 4,921 feet per second during the data collection effort. During the 2007-2008 survey, team members collected 47,433 data points over cross-sections totaling nearly 50 miles in length. Figure E1 shows where data points were collected during the TWDB 2007 survey.

Core samples collected by TWDB were collected at locations where sounding data had been previously collected (Figure E1). All cores were collected with a custom-coring boat and SDI VibraCore system. Cores were analyzed by TWDB, and both the sediment thickness and the distance the core penetrated the pre-impoundment boundary were recorded. Figure E2 shows the soft sediment collected just below the current bathymetric surface at core location #4. At this location, TWDB collected 4.5 feet of sediment, with the upper sediment layers (Figure E2) having a high water content, consisting of fine grained sands to clay material, and lacking in vegetation.

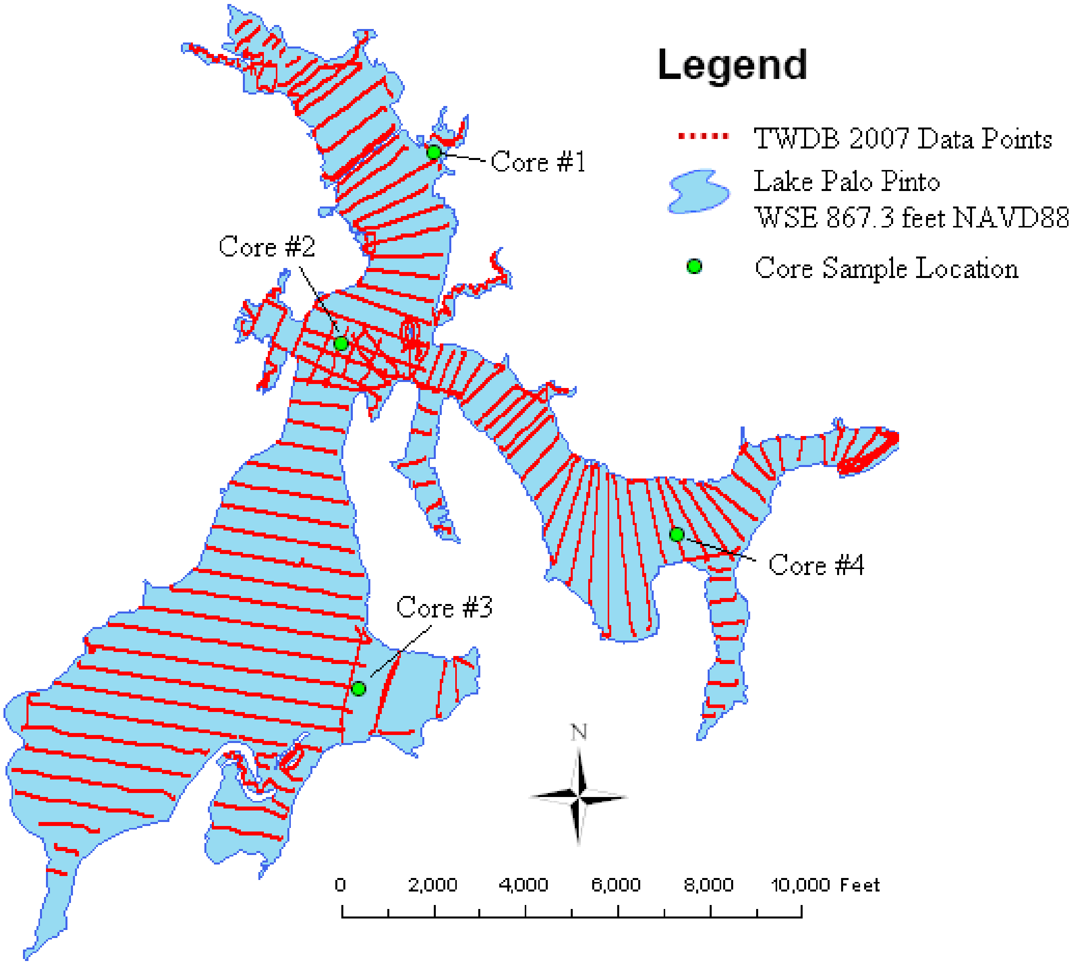


Figure E1 – TWDB 2007 survey data points for Lake Palo Pinto

Figure E2 – Upper portion of core #4 from Lake Palo Pinto, showing fine-grained sediment with high water content and without vegetation.

All sounding data is processed using the DepthPic software, within which both the pre-impoundment and current bathymetric surfaces are identified and digitized manually. These surfaces are first identified along cross-sections for which core samples have been collected – thereby allowing the user to identify color bands in the DepthPic display that correspond to the sediment layer(s) observed in the core samples. This process is illustrated in Figure E3 where core sample #1 is shown with its corresponding sounding data. Core sample #1 contained 1.4 feet of sediment above the pre-impoundment bathymetry, as indicated by the yellow & green boxes, respectively, representing the core sample in Figure E3. The pre-impoundment surface is usually identified within the core sample by one of the following methods: (1) a visual examination of the core for in-place terrestrial materials, such as leaf litter, tree bark, twigs, intact roots, etc., concentrations of which tend to occur on or just below the pre-impoundment surface, (2) changes in texture from well sorted, relatively fine-grained sediment to poorly sorted mixtures of coarse and fine-grained materials, and (3) variations in the physical properties of the sediment, particularly sediment water content and penetration resistance with depth.

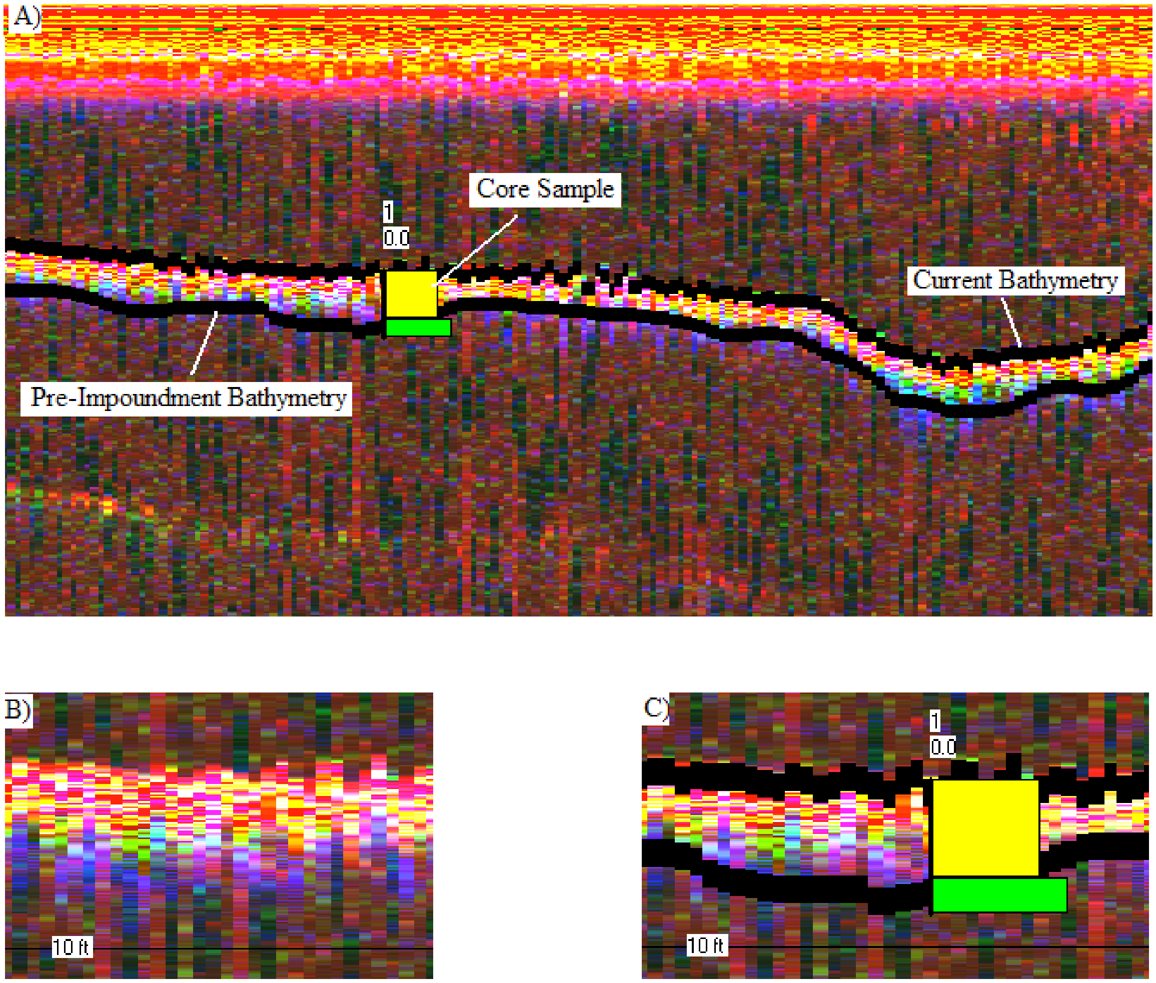


Figure E3 – DepthPic & core sample use in identifying the pre-impoundment bathymetry.

Within DepthPic, the current surface is automatically determined based on the signal returns from the 200 kHz transducer. The pre-impoundment surface must be determined visually based on the pixel color display and any available core sample data. Based on core sample #1, it is clear that the pre-impoundment bathymetric surface for this cross-section may be identified as the base of the bright-colored purple pixels in the DepthPic display. The top of the sediment layer is also clearly identifiable as the band of pink, white, and yellow pixels (Figure E3).

In analyzing data from cross-sections where core samples were not collected, the assumption is made that sediment layers may be identified in a similar manner as when core sample data is available. To improve the validity of this assumption, core samples are collected at regularly spaced intervals within the lake, or at locations where interpretation of the DepthPic display would be difficult without site-specific core data. For this reason, all sounding data is collected and reviewed before core sites are selected and cores are collected.

After manually digitizing the pre-impoundment surface from all cross-sections, both the pre-impoundment and current bathymetric surfaces are exported as X-,Y-,Z-coordinates from DepthPic into text files suitable for use in ArcGIS. Within ArcGIS, the sounding points are then processed into TIN models following standard GIS techniques[1].

Results

The results of the TWDB 2007 Sedimentation Survey indicate Lake Palo Pinto has accumulated 1,850 acre-feet of sediment since impoundment in 1964. Based on this measured sediment volume and assuming a constant rate of sediment accumulation, Lake Palo Pinto loses approximately 42 acre-feet of capacity per year. Sediment is deposited mainly within the submerged channel of Palo Pinto Creek and in the areas immediately adjacent to the submerged channel banks. The maximum sediment thickness observed in Lake Palo Pinto was 6.2 feet, and sediment was observed on 1901 acres (87.3 %) of the lake bed. The average sediment thickness (in areas where sediment is present) is 0.97 feet.

The accumulated sediment volume for Lake Palo Pinto was calculated from a sediment thickness TIN model created in ArcGIS. Sediment thicknesses were computed as the difference in elevations between the current and pre-impoundment bathymetric surfaces as determined with the DepthPic software. Sediment thicknesses were interpolated for locations between surveyed cross-sections using the TWDB self-similar interpolation technique[2]. For the purposes of the TIN model creation, TWDB assumed 0-feet sediment thicknesses at the model boundaries (defined as the 867.3 feet NAVD88 elevation contour and the 864.5 feet NAVD88 elevation contour). Figure E4 depicts the sediment thickness in Lake Palo Pinto.

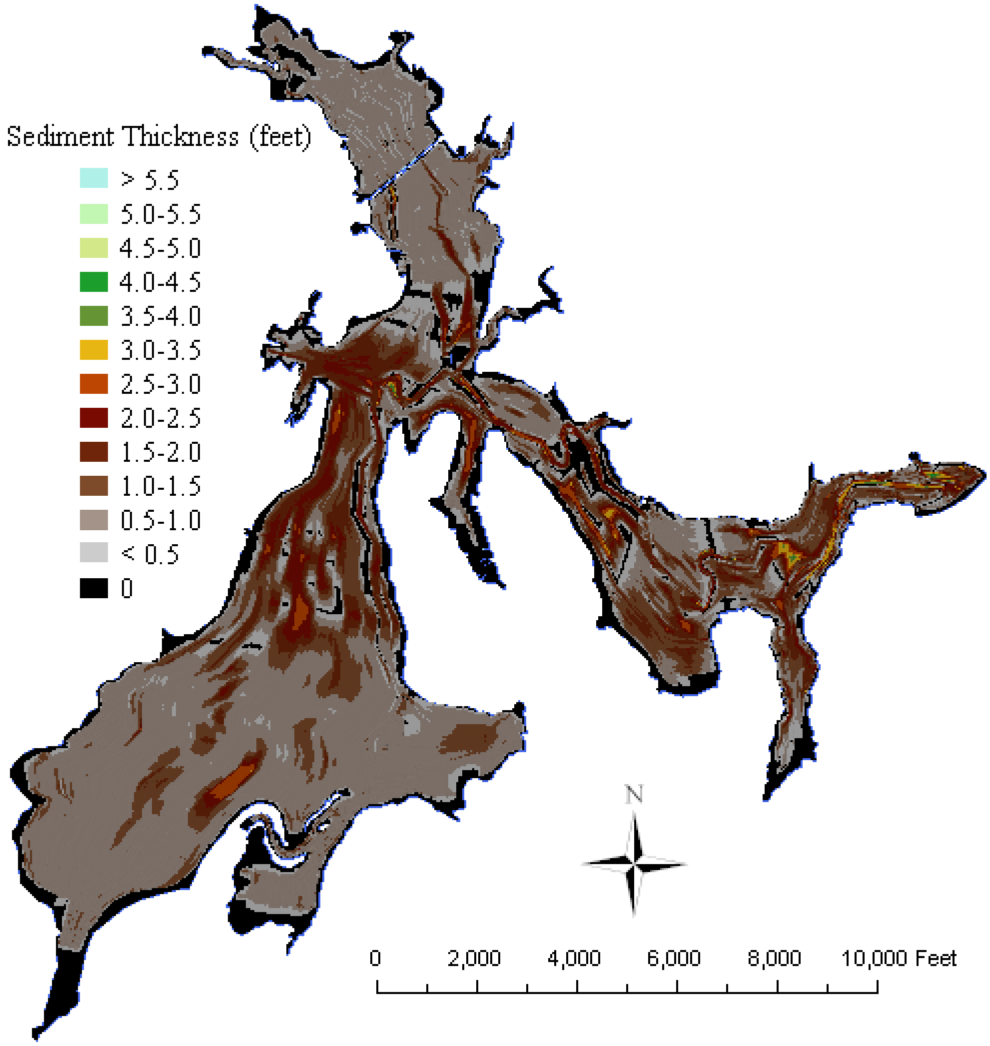


Figure E4 - Sediment thicknesses in Lake Palo Pinto derived from multi-frequency sounding data.

References

1. Furnans, J., Austin, B., Hydrographic survey methods for determining reservoir volume, Environmental Modelling & Software (2007), doi: 10.1016/j.envsoft.2007.05.011
2. Furnans, Jordan. Texas Water Development Board. 2006. "HydroEdit User's Manual."

Figure 5

CONTOURS

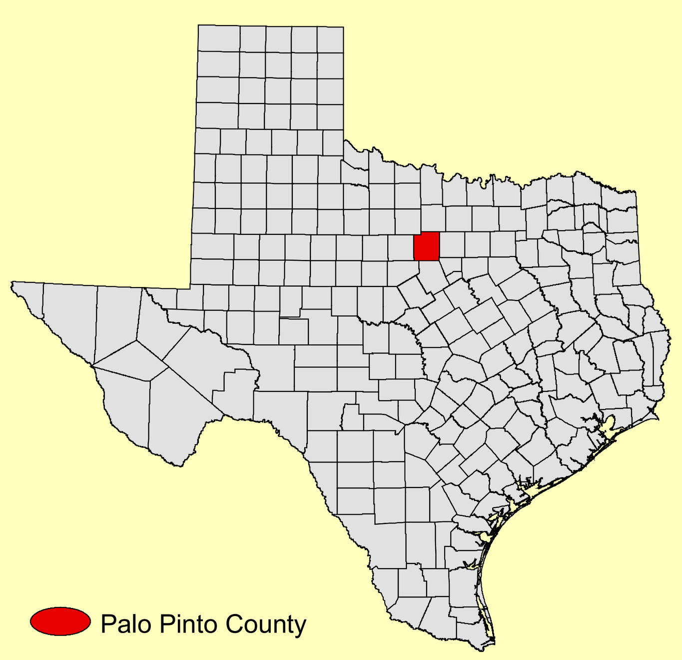
(Elevations in feet)

825'
830'
835'
840'
845'
850'
855'
860'
865'

Islands
Lake Palo Pinto

Conservation Pool Elevation:
867.3 feet NAVD88

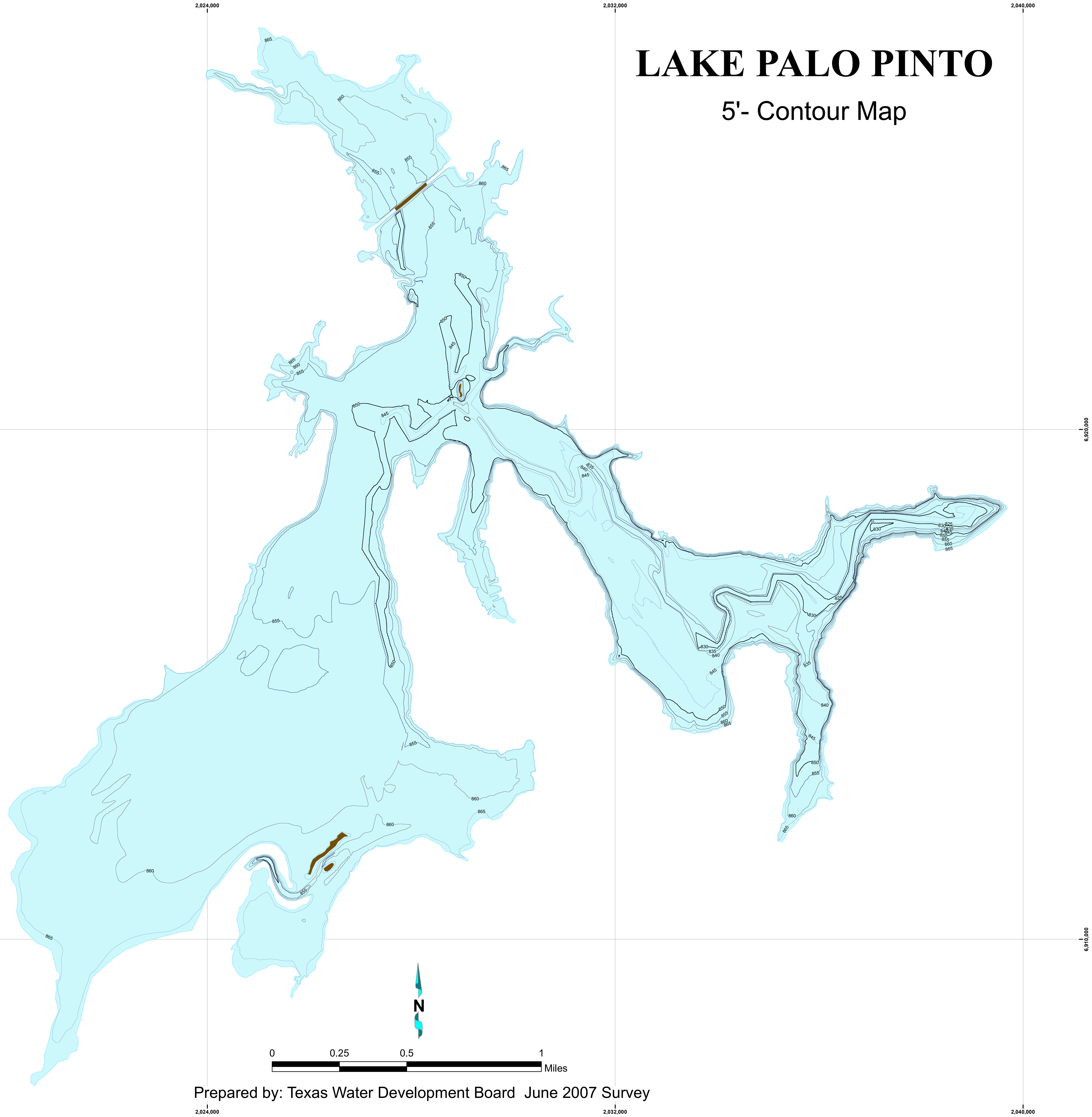
Projection: NAD83
State Plane
Texas North Central Zone



This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Lake Palo Pinto. The Texas Water Development Board makes no representation or assumes any liability.

LAKE PALO PINTO

5'- Contour Map



Prepared by: Texas Water Development Board June 2007 Survey